4

Technical Memorandum No. 33-37

A Recommendation for a Ground-Based and Balloon-Borne Lunar-Planetary Observation Program

In Support of The United States Program of Space Exploration

jpl

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

Revised March 1, 1961

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
CONTRACT NO. NASw-6

Technical Memorandum No. 33-37

A Recommendation for a Ground-Based and Balloon-Borne Lunar-Planetary Observation Program In Support of The United States Program of Space Exploration

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

Revised March 1, 1961

PREFACE

This Report is a summary of the deliberations and the recommendations of the group of people requested by the Jet Propulsion Laboratory to consider what specific steps might be taken in the immediate future to so increase our knowledge of the Moon and planets that the scientific lunar and planetary space probes might be more intelligently and expeditiously planned and their results more fully interpreted.

The material contained herein has been contributed by J. Edson, G. de Vaucouleurs, J. Goldsen, S. Greenfield, J. Hynek, J. Kitchen, and Z. Kopal, and the time and effort represented by their contributions is gratefully acknowledged. Many persons have indirectly contributed to the document; the advice and comments of G. Kuiper and A. Wilson were particularly helpful.

The Report was written by J. A. Hynek, whose assistance in collecting and organizing the discussions and recommendations of the committee is gratefully acknowledged.

CONTENTS

FIGURES

I. INTRODUCTION, SUMMARY, AND RECOMMENDATIONS

Out of concern for the proper and adequate discharge of its responsibility in the lunar and planetary space-probe program of the National Aeronautics and Space Administration (NASA), the Jet Propulsion Laboratory (JPL) created an *ad hoc* Committee on Lunar and Planetary Astronomy. The Committee was asked to formulate specific recommendations as to the manner in which systematic ground-based and balloon-borne observations of the Moon and planets can best be used to aid in the formulation of meaningful space-probe experiments, to aid in the construction and testing of appropriate instruments, and to make possible the fullest interpretation of space-probe data.

It was recognized early in the study that the planning, execution, and interpretation of scientific space-probe experiments cannot be accomplished adequately without information gathered from ground-based observations. As an example, when a probe is in the vicinity of the Moon or a planet, it is patently necessary to have current and past information on the atmospheric and/or surface conditions of that body as seen from the Earth in order to interpret the probe experiment.

The Jet Propulsion Laboratory was not alone in recognizing the importance of ground-based support for space-probe lunar and planetary research. It is of the greatest significance that, during the several months in which the JPL committee met periodically, the spirit and substance of many of the conclusions reached by this committee were voiced independently by other groups, notably by several committees and subcommittees of the Space Science Board. The excerpts presented here serve to illustrate the sharp awakening to the urgent need for implementing space programs by vigorous use of tools already at hand and for effecting a productive union of the respective techniques and knowledge of astronomers and geophysicists.

The Committee on Lunar and Planetary Exploration has urged that planetary studies by Earth-based instruments: i.e., observatories, balloons, and Earth satellites, be encouraged through support and publicity. Much new and important information about the planets can be developed through the use of existing telescopes and through competent personnel that can be attracted to the program if support is available. Balloon telescopes of 20 or 30 inches at 80,000 feet will provide a wealth of information beyond that possible from Earth itself.

The Committee on Ionospheres has recommended that a system of ground-based astronomical observatories be organized in order to provide a continuous planetary patrol, and a subcommittee of the Committee on Biology emphasized the need for more information on the planets, and especially for continuing telescopic studies of the planets. It is especially appropriate that Committee One of the Space Science Board, at its meeting in Arcadia, California, in June 1960, resolved: "The National program for the exploration of the Moon and planets can greatly benefit from the energetic applications of the techniques of ground-based and balloon-borne astronomy. At the present time, the field of lunar and planetary astronomy suffers from inadequate training and personnel. These inadequacies can be remedied with the help of a sum representing a small fraction of the total budget for lunar and planetary exploration. Considering the great scientific value of such observations in the national program, the Committee strongly recommends that NASA consider providing the necessary support."

Not only have formally organized groups commented on the importance of systematic observations of the planets, but individuals have been prompted to make strong unsolicited statements. An excerpt from one of these statements, in a letter from Professor Lawrence A. Manning to Mr. Alan H. Shapley (subsequently circulated by Mr. Shapley to members of the Space Science Board), follows: "Specifically, it seems important to me that every effort be made to increase the amount of work being done in planetary observatories before the need arises to instrument planetary launchings. High quality scientific experiments do not grow in a vacuum . . ."

And further, "The most effective way to stimulate interest appears to be by increasing markedly the support for earth-bound planetary observatories . . .

"Looked at from this viewpoint, ground-based experiments are not competitors of rocket experiments, but are the first step toward developing a national competence in planetary rocket research . . . Thus, strong support for the ground-based planetary program seems to me to be a vital form of insurance for the success of the space program as a whole. I don't see how NASA can fail to have a responsibility to support a program in this area."

Along this same line, Dr. H. C. Urey has pointed out, "We propose to spend enormous sums of money to fly apparatus out there, yet we ignore the handy little devices that lie on our doorstep. It is a very inconsistent attitude."

A. The Status of Planetary Studies

To the uninitiated, it must at once appear strange that a plea for observing the planets need be made by several committees and individuals. Is not observing the planets the proper sphere of the astronomer, and have not astronomers been doing just this for many decades? It might be thought that, in as venerable a science as astronomy, a science which spans billions of light years and encompasses the workings of the universe, the physical astronomy of the closely neighboring members of the solar system would be a virtually perfected science—a completed and well-documented chapter in the annals of astronomy.

It generally comes as a great surprise, therefore, to all but seasoned astronomers that the truth is almost diametrically opposite. Let us take the closest astronomical object, the Moon: The best existing maps of the Moon (Wilkins, Goodacre, etc.) differ only in detail, rather than in kind, from the century-old efforts of Beer and Maedler (1837), or Schmidt (1866), and record, on the whole, only such objects as are visible with telescopes of quite moderate size.

Before we inquire as to why, let us look at the corresponding situation of the planets. One might well think that the planets, the closest celestial objects other than the Sun and Moon (and with them the only celestial bodies that can be telescopically magnified since stars remain "points" of light regardless of the power of the telescope), would have been exhaustively studied and that we would long have been at the stage of diminishing returns. However, the planets have been almost totally neglected by the professional astronomers for the past half-century and more. The reasons are interesting, and some are not without merit.

Foremost among the reasons of merit is the formidable atmospheric barrier which, until very recently, astronomers tacitly believed could not be broken. Several generations of astronomers have been steeped in a tradition of "planetary frustration." They were so acutely aware of the bugbear of atmospheric distortion which vitiated study of planetary details, and which, therefore, invited subjective judgments and barred the impartial testimony of the photographic plate, that they neglected the many worth-while studies that could be made from the surface of the Earth despite the atmospheric frustration barrier and turned their attention to the exciting astrophysical problems of the stellar universe which the Earth's atmosphere impeded but did not bar.

Dr. Fred Whipple, long an exponent of the support for planetary research, has remarked,[1] "This situation, in my opinion, is a natural development from (a) the attitude of the astronomers of the U.S.A. and in other countries, and (b) lack of resources for astronomical research. For the more than thirty years that I have been in astronomy, the professional astronomer has considered planetary and interplanetary research as generally *infra dig.* There have been a few notable exceptions, but very few. Furthermore, those astronomers who were interested in the subject received practically no support, financial or moral, until after World War II, when the military became quite interested in the upper atmosphere and mildly interested in the space beyond."

Dr. Whipple continued: "Now that real space research by space probes and space telescopes has become a reality, the astronomer is in the unenviable position of having failed in providing basic information that could have been obtained from the ground and from balloons. This information about space is sadly needed by the engineers and they are forced to find it by themselves."

This situation was, and is, aggravated by the scarcity of astronomers; it is amusing but also sobering to note that, in a random walk, one's chance of meeting a bank president would be more than one hundred times the chance of meeting a professional astronomer. In point of fact, the total number of astronomers professionally active in all branches of their science does not even at present exceed two thousand all over the world, a num-

[1] Letter to Dr. Frank Edmondson, Oct. 18, 1960.

ber some two orders of magnitude smaller than that of contemporary professional mathematicians or physicists. The relatively few astronomers neglected the planets and instead undertook the task of studying the distant parts of the universe. Even today, only a few astronomers are engaged in the study of the planets. The situation would undoubtedly have been quite different had there been no atmospheric distortion with which to contend.

In addition to these reasons for eschewing planetary studies, there were also those tinged with prejudice and prestige considerations. So promising a field as planetary physical astronomy, abandoned by the great majority of professionals, became an open field for the amateurs, whose spectrum is broad. Unrestrained by the critical surveillance of their professional colleagues, abetted by the perforce subjective nature of the subject, and in some cases moved by private theories and opinions, this group, to put it bluntly, more often than not gave the subject a bad name. The vicious circle was closed by the professionals, especially the newly-minted variety, who disclaimed interest in the planets and the Moon lest they be tainted with the brush of amateurism. Indeed, in the last several decades it would have been difficult, if not impossible, for a young astronomer to have obtained his doctorate in planetary studies at a major institution in the United States. He might almost as well essayed to do a thesis in astrology! During the past 30 years, 3 degrees were granted in France and 2 in the United States for work in the field of planetology.

Where, then, must we look for the manpower to carry out the proposed program in lunar and planetary studies? We must, of course, train more astronomers, but we must also "introduce" the astronomer to the geophysicist, and vice versa. It must be stressed again that a union of astronomers and geophysicists in a common objective of the physical study of the planets is not only desirable but essential. In general, astronomers possess the necessary instruments, the tradition, and the long experience in specialized astronomical techniques, but, most unfortunately, they have not had the interest nor the training necessary to the pursuit of the physical astronomy of the planets, or planetology.

Geophysicists, on the other hand, certainly have the interest and generally the necessary body of theoretical knowledge, but their lack of experience in the techniques and facts of astronomy have prevented them from being acutely aware of the many opportunities for "geophysical" research on the Moon and on the planets. It is most essential, therefore, that a means of effecting this "introduction" and cooperation between astronomers and geophysicists be quickly established.

Now that the frustrating atmospheric barrier has been broken by balloons, rockets, and satellites, it has at long last become not only meaningful (and professionally respectable) to do planetary physical astronomy, but in the scientific guidance of space-probe experiments, it has become a prime necessity. For how can a significant scientific program of lunar and planetary exploration be properly conducted if it is not based on a solid foundation of a consecutive, systematic, observational and theoretical ground-based program, calibrated, interpreted, and greatly enriched and extended by specific observations made from high altitudes.

It should be recognized that it is the possibility of making high-altitude observations which makes a significant ground program feasible. Alone, a ground program would continue to suffer from all the ills attendant upon observing through a turbulent atmosphere. In combination with high-altitude observation, it can furnish the all-important basis for the intelligent planning of space-probe experiments, their instrumentation, and their interpretation, making possible a more greatly enhanced payload of scientific results than would otherwise be possible.

It is well, at this juncture, to state specifically why high-altitude observatories are the key factor in a ground-based program of lunar and planetary observations.

The theoretical resolving power of telescopes is rarely realized in observations from the bottom of our atmospheric ocean. Close approximation of the theoretical resolving power of an instrument could occur routinely from a balloon. The resolving power (*RP*) of a telescope is determined from

$$RP = \frac{4''\!.5}{\text{diameter (in.)}}$$

Thus, a 10-inch telescope has a theoretical resolution of about 0.5 second of arc, whereas one of 45 inches would yield a resolving power of 0.1 second of arc. Greatly reduced atmospheric scattering increases the contrast of dark markings on light backgrounds, and the combination of the two factors should yield routine access to details on the planets and the Moon which are an order of magnitude finer than those seen on the Earth at much more frequent intervals.

Balloons provide an extensive and clear infrared window; detailed infrared photography and spectroscopy of planetary surfaces of a much higher order than heretofore are possible. Infrared observation from the much more infrequent space-probes can be made far more meaningful by reference to a systematic and more frequent series of infrared observations. Not to avail oneself of the potential inherent in systematic observations of the planets and the Moon would be like undertaking a journey into a far land without making the attempt to provide oneself with an atlas and prospectus of such lands. Possession of these items can be of help in determining what one, profitably, should or could do there, and can enrich the results of the journey and the interpretation of these results.

In the present context, the entire space-probe mission would be subject to severe criticism if it were learned that it had been undertaken without maximum reasonable Earth-based observational and experimental support.

B. Recommendations

The conclusions reached by the *ad hoc* Committee are supported in greater detail in the body of this Report, but, in summary, the Committee makes and submits the following recommendations:

1. It is recommended that a small number of existing observatories, at which staff and facilities would permit a planetary observing program, and which are strategically placed with respect to longitude, be encouraged by financial and other material support to enter into a cooperative effort in an accelerated program of lunar and planetary observations, and that such communications facilities as are necessary for the proper execution of the work be provided. It is further recommended that, should additional staff at said observatories be essential to the proper execution of the accelerated program, it be drawn from nationals of the home country of the observatory, but that interchange and exchange of research workers between such observatories be encouraged.

2. It is recommended that, in view of the critical importance of high-altitude observations, a high-altitude balloon facility be established in the United States for the purpose of making lunar and planetary observations, that are not possible from the surface of the Earth, on a scheduled and routine basis in so far as is possible, but especially at those critical times when probes are gathering data in the vicinity of the Moon and the planets and during those periods when the cooperating ground observatories have signaled the occurrence of unusual phenomena or significant changes on planetary surfaces for which detailed observations, unhampered by atmospheric distortion, are essential.

   The committee has learned of plans for a National Balloon Facility to be located in the United States and to be operated cooperatively by several national agencies and universities. In view of this information, the committee recommends that serious attention be given to having the National Balloon Facility meet requirements of the presently proposed program of lunar and planetary observations from balloons. To that end, the committee recommends that NASA be urged to support fully the establishment of a National Balloon Facility.

3. It is recommended that a Data Reduction Center be established to serve as a clearing house for lunar and planetary observations, as a communications and publications facility, and as a focus and study center where the varied techniques and findings of the related disciplines of geophysicists and astronomers can be brought to bear on the study of the planets.

   The committee further recommends that, if the proposed group of cooperating observatories appears unable to furnish an adequate flow of observations, serious consideration be given to the establishment of an observation facility, preferably in connection with the Data Reduction Center, where planetary observations can be carried out without conflict with each other's observational programs—a situation which can easily arise at observatories where several programs of investigation must necessarily compete for telescope time.

4. It is recommended that, because of the highly critical dependence of the quality of ground-based astronomical observations on the "astro-climate" of the observatory site, a comparative study of "astronomical seeing" at the sites of the cooperating observatories be made to make possible the evaluation and intercomparisons of observations made at the several observatories. In addition, a few other selected sites should be similarly evaluated, especially those which are potential sites of a new planetary observation facility. Indeed, whether or not a new planetary observation facility is established should in a large measure depend upon whether or not a site with truly good "astro-climate" in the United States can

be found, for it would be imprudent to establish merely another observatory at a site possessing only mediocre seeing conditions.

In order to be meaningful, such a comparative study should be made with identical instruments and methods.

5. It is recommended that, because of the prospect that the present decade will encompass the launching of numerous space probes and the planning for future generations of interplanetary research vehicles, the proposed program be initiated in suitable phases and budgeted accordingly (see Appendix).

II. THE USE OF GROUND-BASED INSTRUMENTATION

The Committee finds that there is no area of the scientific use of space probes for lunar and planetary exploration which would not benefit materially, and often crucially, by a well-conducted supporting ground-based program of lunar and planetary observations. One program alone, that of lunar mapping, certainly essential to any plans for soft lunar landings, the retrieving of lunar samples, and for the exploration of the lunar surface by instruments, and later by man, would, by itself completely justify the program proposed in this Report. There are in addition, however, supporting programs in lunar patrol, planetary atmosphere, planetary meteorology, planetary surface studies, and planetary patrols which would be invaluable to the space program. The essential features of such programs and their specific bearing on the space program are outlined in this Section.

A. Lunar Mapping

The Jet Propulsion Laboratory of the California Institute of Technology has been assigned by the National Aeronautics and Space Administration the direct responsibility for instrumented soft landings on the lunar surface leading eventually to manned landings and the direct physical exploration of the Moon. The best topographic maps of the Moon must be constructed before such programs can be intelligently carried out. The United States Army and Air Force are, at present, both engaged in such mapping: the Army, by the stereoscopic study of the best photographs obtained over the entire range of the lunar libration; the Air Force, by the photometric tracing of the films on which are continuous records of the shadows of lunar surface objects.

The stereoscopic technique should have the capability to specify the form of the actual lunar surface (i.e., the large-scale deviations of the mean selenoid from a sphere) within errors of the order of 1000 meters; the shadow-tracing technique, on the other hand, appears capable of determining the relative heights of any eminence above the surrounding landscape to better than 10 meters, near the center of the lunar disk.

Stereoscopic measurements represent the royal road for the determination of the altitude levels of different lunar maria, whereas the shadow-tracing technique must be called upon to provide the bulk of the data for local topography. The Air Force maps of the Moon, which are being constructed on the scale of $1:10^6$ and which record all objects down to 0.5 km in size (within 1 km in position at the center of the disk), will essentially depend on the data furnished by the shadow technique.

The great potential of the shadow method can be realized to the degree that continuous observations of the Moon during the entire lunar cycle can be attained, and such continuous observation can be accomplished only if the Moon is picked up sequentially by observations in an east-west longitude chain. As the Moon gets too far west in the sky for good results at one station, it is picked up by the next westward station, and so on, sequentially.

It can be said that, unless there is such a cooperative set of observations devoted to this project, contour mapping of the Moon to the accuracy required by the Army and the Air Force cannot be accomplished for a great many years. An attempt to accomplish such a task from one or two stations would not only require many lunar cycles for each small area on the Moon (even granting perfect weather) but, since the relative position of observer and Moon is not the same at successive corresponding lunar phases, the potential accuracy inherent in the shadow method could not be realized.

The lunar-mapping project alone would suffice to justify support of a set of interlocking observatories for this purpose. It would probably not justify, by itself, the mounting of an extensive balloon project solely for this purpose, but one of the valuable by-products of a balloon program, vital in so many other respects, would be distortion-free observations from high altitudes when such are needed to resolve specific points about critical lunar areas, particularly in the choice of appropriate sites for soft lunar landings.

Further, the high-resolution capability of balloon lunar observatories are certain to be of interest—possibly of crucial importance—to the geologic interpretation of lunar features.

Since both the Army and the Air Force have lunar mapping programs in progress, and the technical capabilities for the necessary computations and analysis, the role of NASA in this instance would be one of cooperative support in furnishing to their programs such material of high accuracy and continuity as would not otherwise be available. It would admirably strengthen existing cooperation between NASA and the military services.

1. Radiometric Mapping

Concerted support is also needed in the radiometric mapping of the lunar surface. A temperature–time map of selected regions of the Moon is an obvious requirement for lunar-exploration plans. A study of the lunar infrared albedo, especially if carried out from balloon altitudes from which an unrestricted infrared window is available, would be of great value in the analysis of the composition of the lunar surface.

With respect to the lunar mapping program alone, it would be sufficient to have a minimum of three ground-based stations spaced about 120 degrees apart, but, since unfavorable weather is certain to occur frequently at any one station, the full complement of the six stations recommended by the Committee would provide the necessary inclement-weather back-up.

Good preliminary information on the surface temperatures of the Moon is available. Increased sensitivity in infrared detection opens the way to finer studies of the spectral distribution of thermal radiation. For example, thermal radiation of a small area of the Moon's surface and its rate of change as it enters the shadow of a lunar mountain depend on the density, thermal conductivity, and heat capacity of the materials of the lunar-surface layers. Measurements at widely different wavelengths (e.g., in the microwave spectrum as well as in the near infrared and the visible) could give all three parameters and a fairly definite indication of the nature of the immediate subsurface layers, particularly the depth and structure of the dust cover in different areas of the Moon. Supporting laboratory studies of terrestrial samples under a variety of environment (vacuum, corpuscular bombardment, thermal gradient) would be necessary for a full interpretation.

2. Lunar Patrol

For many years, astronomers considered the Moon as a totally dead object, and when occasionally some amateur astronomer reported a small change, say, on a crater floor, the report was generally given little weight—often justifiably, since it is notorious to what extent the changing illumination of the lunar surface can cause illusory but convincing effects.

It has recently become apparent that the Moon is a scene of both natural and man-made activity, which introduces the need for a regular lunar patrol. The work of Kozyrev and others indicates that there is now strong evidence of real changes on the Moon. These changes are very possibly the result of residual volcanic activity and the accurate mapping of such areas of activity is obviously of the greatest importance in planned lunar exploration. Kozyrev has furnished strong evidence that the Moon may be a more active object than was heretofore believed.

Recent photographic work at the Pic du Midi Observatory in France has substantiated occasional earlier reports that changes similar (and possibly due to the same cause) to those observed in the region of Alphonsus occur also in the region on the crater Plato. Consequently, continuous survey of this area and a few other suspect areas would be of extreme interest. Such observations, however, cannot be made from any one spot on Earth, which supports the arguments for the establishment of a linkage of several lunar–planetary observatories.

There is also a strong possibility that certain areas of the Moon may be fluorescent, especially in the easily accessible wavelengths $\lambda\lambda$ 4100 to 4300. If a spectrophotometric study reveals particularly prominent fluorescent regions on the Moon, the Moon can be used as an "image converter" for the study of the interception by the Moon of solar particle streams and thus for an investigation of the "solar wind" blowing past the Moon.

The systematic patrol of such regions throughout a period of solar activity would be equivalent to placing a permanent probe at the lunar distance for these purposes; indeed, it might be superior to a permanent probe, for larger sensitive areas could be employed.

As direct aid to the planning of experiments for lunar soft landings, however, a well directed study of the lunar surface almost surely will, because of the great lack of systematic observation in the past decade or so, bring to our attention pertinent questions to be answered by probe experiments, bearing on phenomena which otherwise might escape detection and study.

Finally, extensive lunar observations are essential to the appropriate and adequate interpretation of telemetered information.

Future man-made activity on the Moon will be of two types: planned sorties such as hard and soft landings and eventually manned exploration, of which we will have full information and cognizance, and similar activities of other nations, of which we can expect to have little or no specific information.

With respect to the first type of activity, it is clearly necessary for us to have means of observing the lunar surface at times of the approach of our craft to the vicinity of the Moon. It would be extremely desirable if these times were so chosen as to allow observation from the western hemisphere from both ground and balloon observatories. A positive identification of a landing spot would, of course, be invaluable.

If such occurrences should be visible only from "Russian longitudes," as we may well expect to be the case in launchings not our own, observations made by some observatories in the cooperating chain would serve important purposes. It would be most unwise to be "blind" in Russian longitudes. Since the Moon is scheduled to be the next outpost of mankind, keeping this area under surveillance and concerted study appears to be a most worthy undertaking.

B. The Planets and Planetary Equipment

The opinion has been voiced that, although it is probable the United States may not reap the political and scientific prestige of priority in lunar exploration, the situation may be quite the reverse in planetary exploration. It can be argued that the scientific conquest of the planets requires sophistication of instrumentation, guidance, and communication and planning, and in these the United States excels.

If, indeed, in the long pull the race is for the planets rather than for the Moon, what has been said of lunar observations from the ground and from balloons is even more applicable in regard to the planets. Sophistication of approach, of planning, and of interpretation demands much more knowledge of the surfaces, atmospheres, temperatures, and chemical and meteorological "climate" of the planets than we have at this time. And this, in turn, demands that little time be lost in bringing together not only what knowledge we already have, but bringing together those men, primarily astronomers and geophysicists, who will spawn the ideas leading to the kind of probe experiments that will be profitable and firmly establish and maintain the lead of the United States. As Professor Manning has remarked, "Ideas do not grow in a vacuum."

We cannot wait until probes make scheduled trips to the planets to begin to think of their scientific instrumentation; this must be planned and thought out as soon as possible, and this process can be best generated by men who are working and thinking about these matters, creating and discussing in free forum the rich input of lunar and planetary information which can be gained through modern techniques.

The Committee believes that the climate in which this can occur can be created wholesomely and with relative ease if prompt attention and support is given to the recommended observational and analysis program.

1. Planetary Mapping

Perhaps the most obvious requirements for the planning and interpretation of planetary probe experiments are the best possible maps of the surfaces of the planets to be visited, and it is here that balloon observations offer the greatest promise.

Mercury is the only planet which is, in all probability, airless and on which, therefore, surface changes due to weathering in the usual sense, are not to be expected. In this special case, observations from a balloon are especially important because Mercury can never be observed more than 28 degrees from the Sun, and therefore, only in the morning or evening twilight sky, and only slant-wise through the atmosphere. Turbulence and haze in the atmosphere are therefore extremely troublesome and have never allowed the full resolution capability of ground-based telescopes. Since Mercury shows the full phase only when very close to the Sun, attempts at mapping have met with little success. Observations from balloons would not only free the observer from near-horizon turbulence but would provide the necessary much greater contrast between Mercury and its sky background. One careful map made from balloon observations should serve until probes can fill in the details of the skeleton mapping possible to observers at the Earth's distance. It can clearly be anticipated that our knowledge of Mercury will be extensively increased by systematic observation from balloons.

All other planets likely to be the subject of probe experiments exhibit relatively rapid surface changes. Venus, which has a cloud-covered surface, shows vague, short-lived markings which, oddly, are more pronounced in the ultraviolet than in the visual or the red. Here again, balloon observations will provide high-contrast, distortion-free observations which may help disclose the true nature of these markings.

2. Features of Mars

Mars is the only neighboring planet with a surface and markings which can clearly be seen; that is, to the limit imposed by our atmosphere and sometimes, to a marked degree, by the atmosphere of Mars. Because of the threshold character of the visibility of Martian features, their form, changes, and even existence have been the subject of much controversy. The concensus, however, of many observers is that a majority of the changes observed on Mars are real and that there is in fact a network of "something" on Mars which does undergo real changes (see Fig. 1).

There is, therefore, an obvious need for good maps of Mars. A map currently in production at Harvard Observatory and the University of Texas covers observations from 1909 to 1958 and comprises 17,000 individual observations. This map will anchor first-order points on Mars to a much higher accuracy than previously attained and should allow one to determine, for instance, whether or not the mean rotation of Mars is constant.

The great need, however, continues to be to pinpoint real changes on Mars, for which basic maps are a prime necessity, and this can best be done from balloons. For instance, if successive photographs of Mars were taken, one frame every 30 seconds, from a high-altitude balloon, it would give us a unique record of Martian features and surface events. The value of such in the physical study of Mars is self-evident.

A Mars patrol is highly desirable. Since the rotation period of Mars is only slightly greater than that of the Earth, the eastern hemisphere of the Earth sees a hemisphere of Mars invisible to the western hemisphere, and vice versa. Not until a period of about two weeks is past does the situation reverse. In order to interpret the changes on the Martian surface, future systematic photographs of Mars will be necessary for comparison with the Harvard–Texas Observatory map now in preparation.

The seasonal variations of the Martian polar caps is well known, but there are many variations suspected, variations which may have a close correlation with solar activity. Detailed studies of the polar caps should lead to realistic estimates of the total amount of surface water available on Mars, a point of considerable importance to planners of Martian probe experiments and of eventual landings.

The surfaces of the major planets are buried far below extensive atmospheres. Their satellite systems should be studied as possible future landing sites and bases, especially the large satellite systems of Jupiter and Saturn which should be investigated by photography, colorimetry, and photometry. By extension, the larger asteroids fall into this category, for they may well serve in the future as interplanetary bases.

C. *Planetary Atmospheres*

As accurate knowledge as possible of the atmospheres of planets is clearly essential to the planning of probe experiments designed to obtain detailed information on planetary environments. More directly, we must know what information we are seeking before we design experiments for those purposes. In many respects, the problems of atmospheric extent and composition are an order of magnitude easier than those relating to surface details, where one must do continual battle with terrestrial atmospheric distortion, and to finite resolving power of telescopes and photographic plates. Unless one is concerned with the spectroscopy, photometry, colorimetry, or radiometry of a restricted planetary area, these two obstacles are not too severe. However, observation from balloons is needed to obtain a free infrared window, which is a prime necessity, especially for spectroscopy, since molecular bands lie almost entirely in this region.

In the area of extent, transparency, and composition of planetary atmospheres, again it is almost unthinkable to contemplate the conception and design of probe experiments, and their subsequent interpretation, without the new wealth of information an Earth-based program promises.

Present probe-experiment planning owes much to the growing body of information on the nature of planetary atmospheres, much, however, garnered only in the last few years. Later generations of sophisticated experiments will, in all probability, be based on ideas that most certainly will spring out of the analysis of the data from systematic, cooperative efforts to observe the planets from here on Earth.

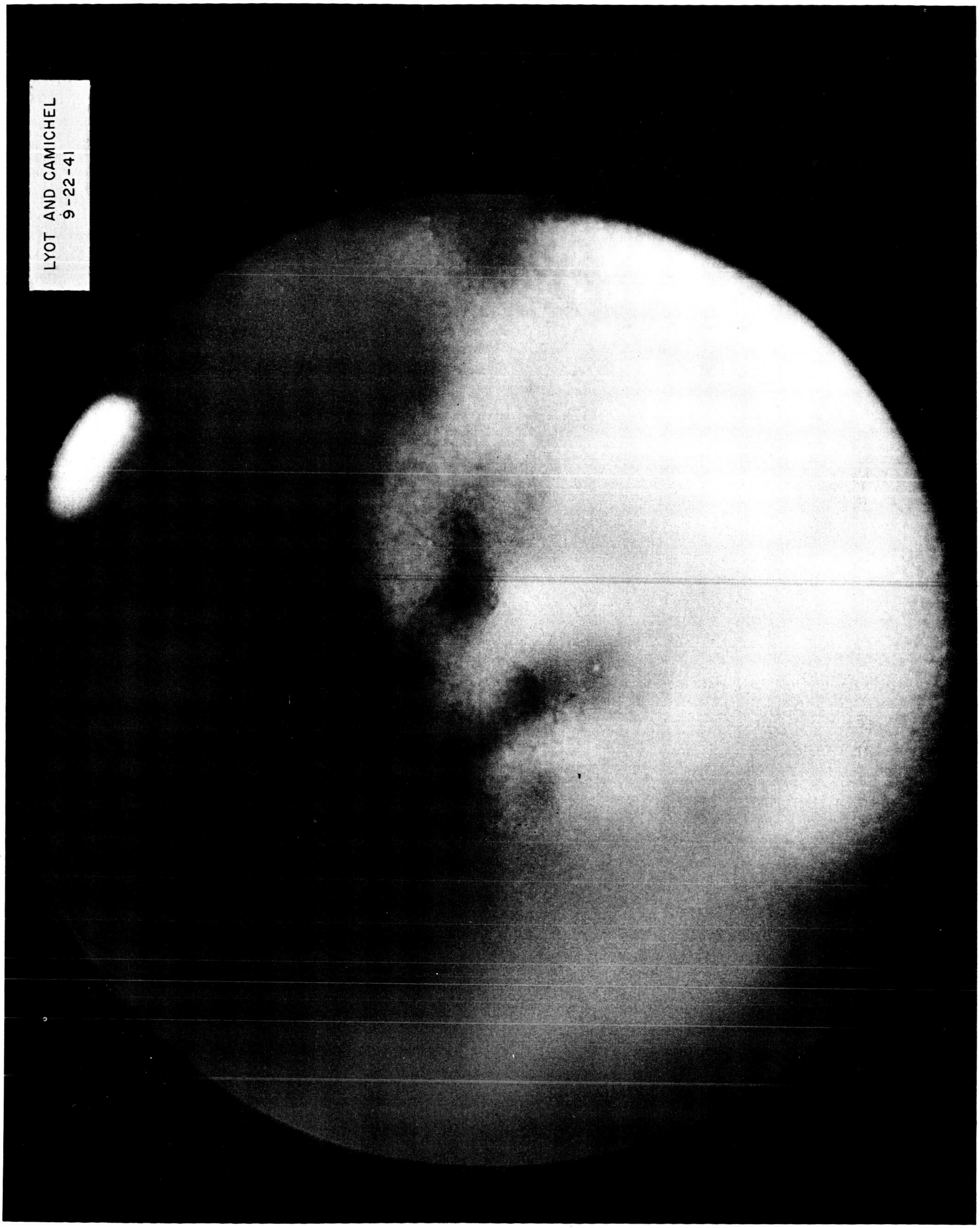

Fig. 1. Mars observed from Pic du Midi

1. Planetary Probes

The nature of the perpetual cloud cover on Venus is not yet known. If this can be determined in the near future, it will dictate a whole family of probe experiments which could not now be outlined. More is known, however, of the extent, temperature, and pressure of the atmosphere of Venus above the cloud layer—largely because of the recent analysis by de Vaucouleurs of the 1959 occultation of Regulus by Venus. This rare phenomenon (it occurs only once every several centuries), in which the light of Regulus was differentially refracted by the upper reaches of the Venusian atmosphere, made possible the determination, to far greater accuracy than before, the scale height and other constants of the atmosphere of Venus, as well as the diameter and orbital position of this planet.

The occultation of bright stars by the planets is a rare phenomenon, but the occultation of faint stars is far more frequent. The observation of such occultation by Mars, which could be done especially well from balloons, will give us a much better determination of Martian atmosphere constants than are now available.

The determination of the limb darkening of a planet, by photoelectric traces made across its disk (and again far better made from high altitudes) is needed to give information on the extent, the density, and the scattering properties of the planetary atmosphere. Polarization measures, especially at short wavelengths, would be useful for the determination of atmospheric scattering.

A Mars probe experiment of great possible significance would be one concerned with the puzzling marked variable transparency of the Martian atmosphere, especially in the short wavelengths. Before this experiment can be designed, however, more information is needed on the phenomenon of the "blue haze" and on the frequency of the "blue clearing."

The unusual opacity in the violet of the Martian atmosphere is quite distinct from that of the heterochromatic haze, probably ascribable to a Mars-wide "dust storm," which on occasion obliterates all detail on the disk of Mars. This occurred, for instance, during the 1956 opposition when, despite Mars' relatively close approach to the Earth, little detail could be discerned on the Martian surface. The blue haze is a highly color-selective obliteration and causes the Martian atmosphere to be virtually opaque in blue and violet light, although yellow and red photographs are little affected. A "blue clearing" occasionally occurs, and quite suddenly the atmosphere becomes temporarily blue-transparent. The suddenness with which the clearing occurs suggests that the scattering particles may precipitate out of the atmosphere, or that blue transparency is dependent on the phase angle, the angle formed at the Earth between the Sun and the planet because, perhaps, of a preferential orientation of the blue particles. The phenomenon has not been sufficiently observed to know whether or not it always occurs near (say, within 80 days of) opposition (when of course the probability of its being observed is highest) or if occasionally it occurs at other times; only sustained observation in a coherent program can settle this and, in turn, suggest fruitful probe experiments on the nature of the scattering medium.

Cloud motions in the atmosphere of Mars should be determined on those occasions when clouds are visible; on Venus, which is perpetually cloud covered, if cloud motions could be delineated by the study of transient markings on ultraviolet time-lapse photographs, a valuable clue to the still unknown axial rotation period of Venus might be gained, as well as, of course, synoptic meteorological data.

2. Planetary Temperatures and Climate

Knowledge of the basic climate of Mars and Venus, particularly the seasonal temperature means and extremes, are fundamental to probe planning, and this again calls for a systematic planetary observational program. Here, infrared and microwave radiometric measures are especially indicated. Good preliminary information on the surface temperature of Mars and on the atmospheric temperatures of Venus is already available. It should be extended, however, particularly as to position and time variation in order that detailed spot measures from probes can be meaningfully integrated into the whole planetary climatic picture. Increased sensitivity in infrared detectors opens the way to finer studies of the spectral distribution of planetary thermal radiation.

a. Atmospheric composition. A volume might be written on the potentialities of the spectroscopy, particularly in the infrared, in the study of the chemical constitution of planetary atmospheres. The outstanding puzzle, the nature of the dense cloud cover on Venus, is ripe for attack, especially from high-altitude balloons. Even preliminary information from Earth-based observations is certain to spawn a generation of probe experiments.

What are the amounts of N_2, CO_2, H_2O, O_2, in the atmospheres of Mars and Venus? What is the primary cause of the high opacity of the Venusian atmosphere?

How far below the top of the opaque cloud layer does the surface of Venus lie? These questions are basic to detailed probe experiments, and can be attacked not only spectroscopically but by colorimetry, radiometry, and polarimetry.

b. The twilight and the unilluminated zones of Venus. The portion of Venus not illuminated by direct sunlight has, nonetheless, a residual glow which appears too bright to be explained as ordinary night atmospheric glow. As in so many previous examples, before specific probe flights to explore the night side of Venus are made, a balloon-based spectroscopic study of these areas of Venus should, in fact, must, be made. It is important to note that the strongest lines in the spectrum of the night sky of Venus are as yet unexplained. Particularly important would be a study of the bands of N_2. Greater proximity of Venus to the Sun would, if Venus has an appreciable magnetic field, produce extensive Van Allen belts and, hence, intense auroral displays. A Venus auroral patrol would provide first-order information on the magnetic field of Venus. Probe instrumentation for an examination of the magnetic field of Venus is already in preparation and ground-based back-up of this type would be valuable.

c. Solar–planetary relationships. A Venus auroral patrol might determine the correlation between solar–terrestrial and solar-Venusian relations. Are aurorae on the Earth and on Venus correlated?

Apropos of solar influence on members of the solar system, the observation of comets and asteroids offers some promise. It is very likely that a burst of solar activity is reflected in the activity of comet tails. Although bright comets are rare, there are almost always some minor comets in the sky. Further, the object Schwassmann-Wachmann, a "cross" between an asteroid and a comet, although traveling in an asteroid-like orbit, behaves more like a comet. It never develops a tail but appears more as a comet head and undergoes striking changes in luminosity. In a matter of hours, it can change more than a magnitude in brightness. Here is an object which would warrant patrol, with balloon observations whenever possible.

D. Summary

The foregoing discussion might be highlighted by the simple statement that the scientific pay-off per probe-payload pound will depend to a large extent (1) upon the ability to correctly forecast and delineate the physical conditions on and near the target planet, ensuring that probe experiments are not shots in the dark but are designed to answer specific and sophisticated questions, and (2) on detailed Earth-based observations before, during, and after intercept by a probe, as vital interpretive back-up for the probe experiment. At critical epochs, full use should be made of the gain in photographic resolution offered by a balloon telescope over Earth-based telescopes; this is a gain of about four, which implies a gain of sixteen in information, since area is the more significant quantity.

Intensified programs of ground and balloon observations in the time-vicinity of a probe arrival at a planet should be an integral part of a probe firing routine. It would be reprehensible and foolhardy to leave anything to chance that did not have to be so left, and it could easily generate such criticism in the scientific world as to jeopardize the entire scientific space program. For instance, a high resolution TV picture of a region of Mars might be taken by a probe at a time when the surface of Mars was covered by a yellow dust storm, or when a blue haze obliterated surface details. Earth-based observations could supply this information, which would obviously be needed to interpret the probe results.

Again, the interpretation of close-up photographs of the darkish regions of Mars and scans of their infrared reflection spectra would gain greatly if the seasonal conditions and the nature of the region, permanent or temporary, were precisely known from Earth-based observations; the seasonal variations do not repeat with clockwork precision on Mars any more than they do on Earth—the seasonal darkening wave may be several weeks behind or ahead of schedule. It may well be that, say, the infrared spectrum of a region will depend on whether or not the region has been activated by the seasonal cycle. Careful photometric observations, with sufficient continuity, of the planet for several months before and after the time of probe intercept will be needed to determine these circumstances.

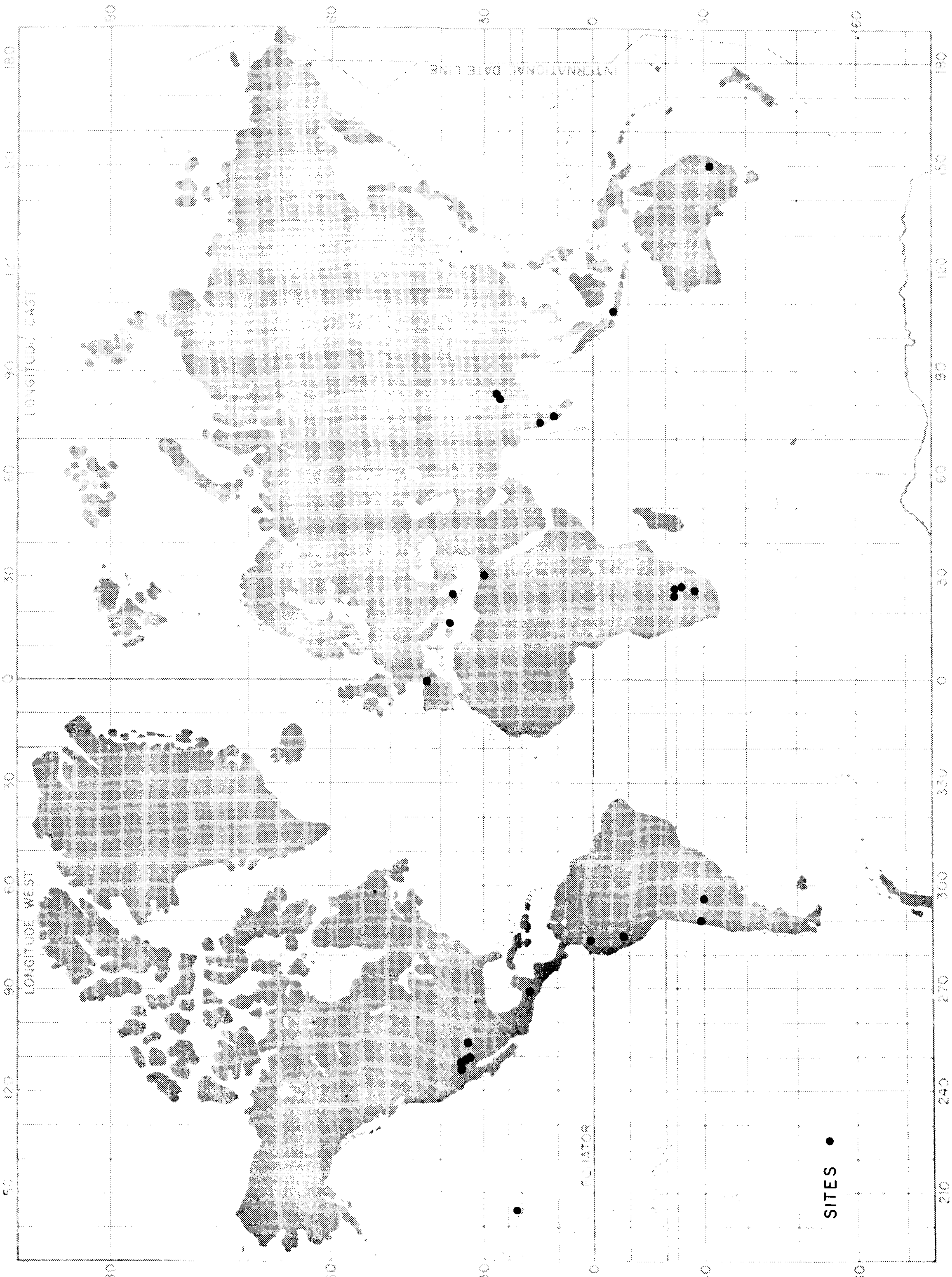

Fig. 2. Possible observatory sites

III. THE WORLD-WIDE POTENTIAL FOR LUNAR AND PLANETARY OBSERVATIONS

The Committee finds that there are about twenty-five existing observatories around the world which appear to be potential members of a lunar–planetary observing network (Table 1). From this number, the Committee recommends that about six be selected. The possible sites listed in the Table and shown on the accompanying map (Fig. 2) are classified according to probable availability and capability for the contemplated work. There has been no discussion as yet with the directors of respective observatories; hence, the estimates given in the Appendix represent only a subjective evaluation by the Committee and may change radically after direct contacts are made.

The potential sites are divided into four classes:

1. Observatories already engaged in the lunar and planetary field which would, therefore, require only additional supporting personnel, equipment, and financing (for example, Pic du Midi, Fig. 3).

Table 1. Existing observatories

Serial number	Location	Class	Longitude, deg	Latitude, deg	Present equipment
1	Pic du Midi, France	1	0	+43	40-in. reflector* 24-in. refractor
2	Athens, Greece	1	−24	+38	15-in. refractor 26-in. refractor*
3	Catania, Italy	1	−15	+37	15-in. refractor
4	Kwasan, Japan	2	−135	+35	24-in. reflector
5	Boyden, Bloemfontein, South Africa	2	−26	−29	60-in. reflector
6	Oliphantsfontein, South Africa	2	−28	−26	Baker-Nunn
7	Johannesburg, South Africa	2	−28	−26	27-in. refractor
8	Kodaikanal, India	2	−77	+10	20-in. reflector 60-in. reflector*
9	Naini-tal, India	2	−80	+29	10-in. refractor Baker-Nunn 15-in. reflector
10	Lembang, Java	2	−107	−7	24-in. refractor
11	Lowell, Arizona	2	+111	+35	24-in. refractor 42-in. reflector 69-in. reflector*
12	McDonald, Texas	2	+104	+31	36-in. reflector 82-in. reflector
13	Sacramento Peak, New Mexico	2	+106	+33	Coronagraph and assorted small instruments
14	Arequipa, Peru	2	+70	−12	Baker-Nunn
15	Mt. Stromlo, Australia	3	−149	−35	74-in. reflector
16	Pretoria, South Africa	3	−28	−26	74-in. reflector
17	Helwan, Egypt	3	−31	+30	75-in. reflector
18	Nizamia, Hyderabad, India	3	−79	+17	48-in. reflector*
19	Kamagota, Japan	3	−140	+40	74-in. reflector
20	Santiago, Chile	3	+70	−33	60-in. reflector*
21	Tokyo, Japan	4	−140	+36	*
22	Tonantzintla, Mexico	4	+98	+19	40-in. reflector*
23	Haleakala, Maui, Hawaii	4	+156.5	+20.5	Baker-Nunn
24	Quito, Ecuador	4	+78	0	—
25	Bosque Alegre, Argentina	4	+64	−31	61-in. reflector
26	New Mexico	4	+106	+33	—

NOTE: Asterisk indicates equipment is projected or under construction.

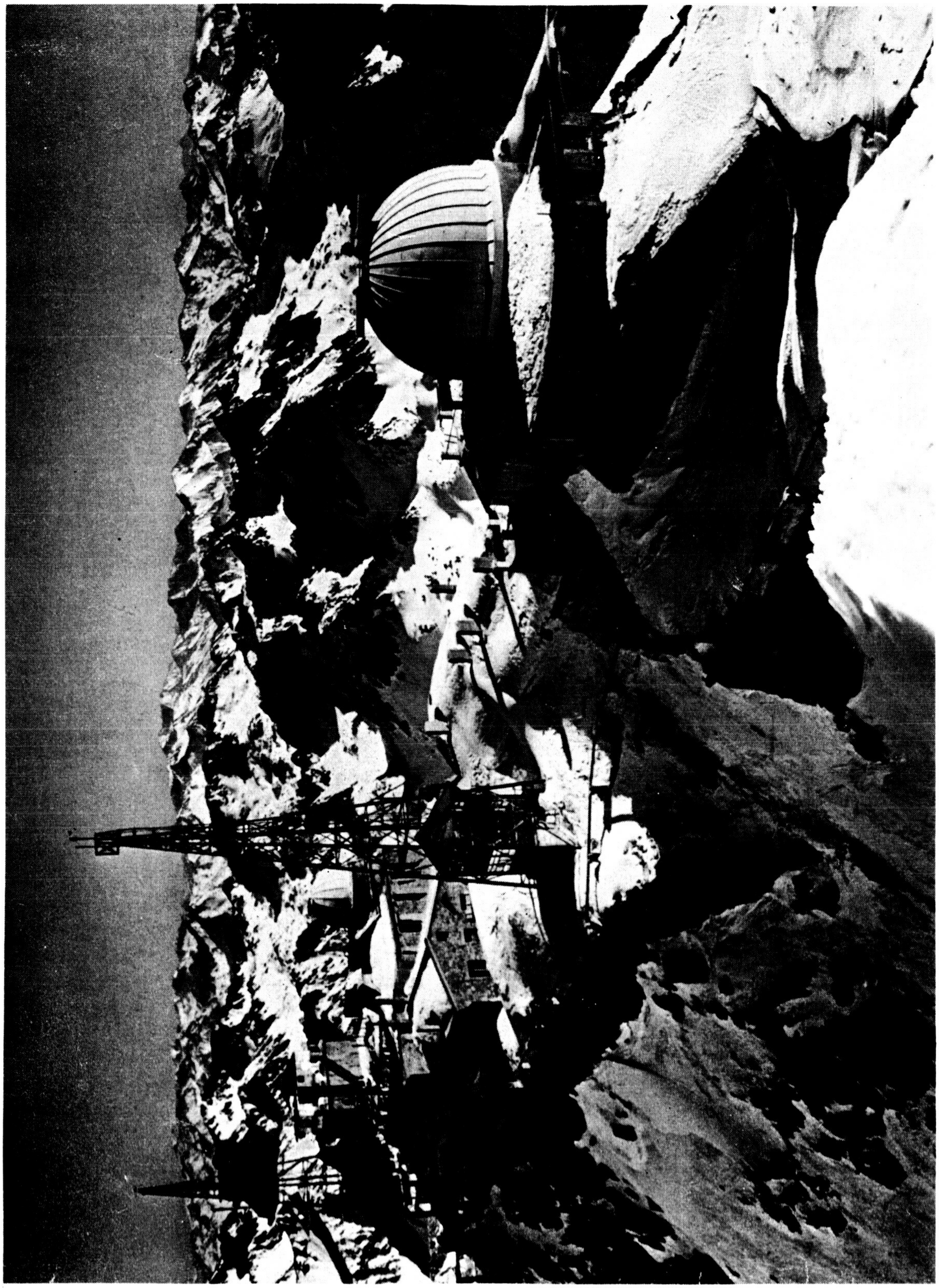

Fig. 3. Pic du Midi Observatory (Sky and Telescope)

2. Observatories where potential interest in lunar and planetary astronomy is known to exist but which have not recently been active because of other commitments and/or limited scientific facilities.
3. Observatories which, because of favorable position or special equipment, could contribute to the program but which have no previous record of active interest in the field.
4. Sites associated with present observatories which would be especially desirable for inclusion because of favorable geographical location in the network.

Only three observatories fall into the first category, nearly a dozen fall into the second category, and six observatories fall in each of the last two categories. In category 4, however, one might well include all the 12 sites at which the Smithsonian Baker-Nunn optical satellite stations are presently located. These observatories are under unified control, and it appears probable that special arrangements could be worked out with the Smithsonian Astrophysical Oservatory whereby the existing sites, with their associated power, water, and living facilities, might be utilized in the establishment of special small planetary observatories.

The cost estimates for supporting present work and for initiating new programs are given in the Appendix, but it would appear that each of the stations finally selected might be operated at a yearly cost of approximately $15,000.00, exclusive of the cost of the equipment to be furnished.

The full complement of the six observatory sites to be selected need not be simultaneously activated, but immediate attention should be given to active support of two or three observatories at which vital interest in the area is known to exist (as attested to by recent results) and to the rest of the observatories as both arrangements with local authorities and budget considerations allow. However, within two years, four, or perhaps as many as six, sites should be essentially completed in order that a meaningful systematic program can be in progress.

IV. THE USE OF BALLOON-BORNE INSTRUMENTATION

The outstanding fact that present high-altitude balloons make possible scintillation- and distortion-free observation of the Moon and planets (thus releasing the astronomer from his traditional *bête noire* "astronomical seeing," including all the phenomena covered by this omnibus term) makes the use of the balloon techniques essential to a lunar–planetary observational program. Any suggested program not encompassing this technique would be open to grave criticism for not utilizing a means of obtaining unparalleled new results and one which furnishes interpretive back-up to a ground program.

The importance of balloon observations in the proposed program of observations, and the great technical potential that a balloon facility can offer a space program, has been briefly outlined in Section I. With the exception of observation in the ultraviolet region of the spectrum (and this is not entirely excluded), and of the limitations imposed by observing the planets at the Earth's distance, the balloon is as unhampered as the space probe itself. In the visual and in the infrared regions, the balloon is far superior to artificial satellites: its payloads are greater and observations are directly recoverable. It is a mistake in this sense to look upon balloons as a way-station to orbiting observatories, soon to be obsolete. Indeed, were it practical, even greater use of balloons in this proposed program would be recommended. At present, however, we must be content to urge a single balloon facility located at a favorable site, preferably in close proximity to the site of one of the group of cooperating observatories.

It is apropos to note a recommendation of the Committee on Optical and Radio Astronomy of the Space

Science Board that balloons be used in preference to satellites for high-resolution studies of the Sun and the surfaces of the planets and for the spectroscopy of planetary atmospheres. This Committee also stressed the potential application of balloons to millimeter-wave radio astronomy, in particular for the absorption studies of planetary atmospheres . Reference is also made to a paper by J. R. Smith[2] which presents, in tabular and graphical form, the altitude-payload relationship for various types of balloons.

From all present evidence, it appears that floating altitudes of 70,000 to 80,000 feet will suffice for lunar and planetary observations; hence, relatively modest balloon sizes and weights can be employed.

A side consideration, not directly germane to the problem at hand, but nonetheless closely related through underlying factors of national prestige in the space program, is the fact that the Soviet Union, for reasons unknown, does not seem prepared or equipped to exploit the balloon technique which was pioneered and developed primarily in the United States. The full exploitation of the experience and capability already demonstrated by the United States is clearly a marked way of achieving both spectacular and quiet solid advances in space exploration. It is an opportunity not to be overlooked, even apart from the thesis of the present Report.

A criticism frequently directed toward balloon astronomy is that balloon launching is a haphazard matter not subject to schedule because of stringent meteorological requirements. This condition is being rapidly corrected by the introduction of new launching techniques. The Atomic Energy Commission has successfully launched as many as 100 scientific payload balloons per year. Further, the use of the natural windscreen technique has demonstrated in practice that judicious use of natural box canyons allows launching to approach a scheduled basis. The region around Alamogordo, New Mexico, provides a number of such natural windscreens. It has already been suggested, by advocates of a National Balloon Facility, that close cooperation with the already existing Air Force Balloon Facility at Alamogordo might be established. A similar suggestion might be made with respect to the present proposal.

A. Advantages of Balloon Observations Over Ground-Based Observations

It is well, at this point, to further document points touched upon in Section I relative to the great potential of observations made from balloons.

[2] *On the Use of High-Altitude Balloons for Astronomical Platforms.* Raven Industries, Inc., 1960.

It could be said with considerable justification that almost any astronomical observation made in the past several centuries could today be better made from a balloon, given a suitably stabilized platform. Apart from the extended spectral region available and greater freedom from scattered light, the ability to observe free of the frustrations of atmospheric distortion is in itself an astronomical prize of great value. This one factor alone allows a given telescope to function at or near its theoretical resolving power; the resulting stellar images are consequently much more concentrated, and significantly fainter stellar magnitudes can be reached. Such distortion-free images will be smaller in diameter by a factor of three or four, and sometimes much more, and thus smaller in area by an order of magniture; objects two or three magnitudes fainter than previously attainable can be reached. A balloon-borne telescope, with adequate supporting stabilization, is for these purposes the equivalent of a ground-based telescope of two-to-four times greater aperture diameter. In the optical detection of space probes, this factor is very important since every stellar magnitude gained in faintness limit is equivalent to increasing the distance by a factor of 1.6.

In order to make use of these potential advantages however, images must be stabilized to the same order as the theoretical resolving power of the telescope used, which means, in most cases, angular rates less than 0.1 second of arc in several seconds of exposure time.

B. Planetary Details and Diameters

At balloon altitudes there is no image blur, distortion, or scintillation, therefore lunar and planetary details can be delineated in a manner totally impossible from the surface of the Earth. For this reason, it is impossible to predict what wealth of detail will be revealed by even a modest telescope used under these ideal conditions. We approach here the area of the unpredictable and unexpected in science (in science it is the unexpected that happens). Another contributing factor is that at these altitudes we also have freedom from the scattered light always present to some degree in the lower atmosphere which scatters light into a planetary image, thereby decreasing contrast discrimination (the familiar glare or aureole around the Sun, easily noted by holding the edge of a coin as close as possible to the Sun's limb, is, of course, present for fainter celestial sources).

Another factor is the increased brightness of a planetary image from balloon altitudes caused by the almost total elimination of the extinction factor, a measure of the light extracted from the image by absorption and scattering. Particularly for observation of planets from the northern hemisphere, from which the planets must very often be observed at low altitudes in the sky (the most favorable oppositions of Mars always occur when Mars is south of the celestial equator), the virtual elimination of the extinction factor would aid materially by reducing exposure times.

It can be safely predicted that, taking into account all the advantages of balloon astronomy, photographs of the planets taken from balloons will greatly exceed in quality even the best obtainable on the ground. It is obvious that photographs with such detail are essential to the best interpretation of rocket-borne experiments.

Balloon observation of planets will allow the precise determination of planetary diameters because of the freedom from the ever-present "boiling" of the Earth-viewed image. A steadily shining, well-defined planetary image offers interesting possibilities for the guidance of space probes. The size of the image can be used as an index of distance from probe to planet.

C. Occultations

The absence of stellar-image scintillation will yield photoelectric light traces of unparalleled clarity; this opens new vistas in astronomical photometry which find direct applications in the study of planets and in space-probe planning and interpretation. One such application lies in the high-precision study of stellar occultations by planetary atmospheres from which accurate data can be secured about the composition and temperature of the upper atmospheres. At ground level, because of atmospheric turbulence, it is not possible to use field apertures smaller than about 6 to 8 seconds of arc; consequently, most of the light measured arises from atmospheric scattering and only a small part from the star, which must be very bright to be observable at all. Also, it is not possible to observe the phenomenon at the bright limb of the planet; at stratospheric altitudes, the use of a field aperture 0.5 second of arc or less in diameter would be possible; with the reduced sky brightness, this would provide a gain of over 10 magnitudes (a 10^4 ratio). This would completely revolutionize the application of this technique which is at present difficult but is potentially a very powerful means of optical probing of the upper layers of planetary atmospheres[3].

The occultation of Regulus by Venus, which produced such exemplary results in the study of the upper atmosphere of Venus, occurs rarely, even in the historical time scale. However, the occultations of fainter stars by the planets is a relatively frequent occurrence, although unfortunately occultations of such faint stars cannot be adequately observed from the surface of the Earth. From a balloon, however, the situation is different, and the occulted faint star can be utilized as an optical probe of the planetary atmosphere.

D. Infrared Studies of the Earth

The unhampered use of the entire infrared and microwave region of the spectrum is of paramount importance, as has already been emphasized, in the molecular analysis of planetary atmospheres.

The Earth is the only planet, at present, whose atmosphere can be studied in depth. Not only can improved studies be made at various levels of the Earth's atmosphere by means of balloons, but a balloon can be thought of as a very close approaching probe to a planet well worthy of study–the Earth.

A given probe experiment should be tried against the Earth, as a test planet, in the presence (in the balloon) of larger scale, auxiliary equipment which will increase the interpretive potential of the specific probe experiment.

E. Development of Spacecraft Components

A balloon facility offers a remarkable capability for the development and testing of components (improved sensing and homing, attitude control, radar sounding, etc.) intended for probe use in the vicinity of the target planet. It may indeed be advisable and profitable to subject all probe-intended instrumentation to operational tests in balloons, insofar as these instruments are not dependent on zero-weight properties.

F. Existing Balloon Programs

It is most fortunate that, at this juncture in this particular phase of the balloon observational program planning, there already exist several balloon astronomy programs which have borne the brunt of much development work. Therefore, the sums here envisioned for additional development work are indeed modest.

The directors of these several programs are cognizant of and sympathetic to the present proposed program. It can be anticipated with confidence that much of the stabilization and control gear and techniques developed by these programs can be utilized directly in the proposed program. These current programs include: the National Science Foundation–Office of Naval Research–NASA

[3]De Vaucouleurs, G. H., and Menzel, D. H., *Nature*, 188:28–33, 1960.

Stratoscope Program directed by Dr. M. Schwarzschild which is developing stabilization systems capable of 0."1 stabilization (see Fig. 4); the Air Force–Northwestern University–MIT manned-gondola balloon astronomy program (see Fig. 5); and the Navy-sponsored Stratolab series of manned flights for atmospheric and astronomical purposes.

The significance of the scientific results already obtained by means of high-altitude balloons is well recognized and demonstrates the capability of the balloon technique.

G. Comparison with Satellite Observatories

Observations in the far ultraviolet region of the spectrum cannot be made from balloons. Such investigations require equipment located above the ozone, oxygen, and nitrogen of the atmosphere; for example, on an orbiting observatory. Such an orbiting observatory could, in principle, carry out the other observations which are described here as part of a balloon program.

The development schedule for an Orbiting Astronomical Observatory (OAO) calls for a first flight in 1964. Such an observatory might be available as a planetary research tool in the second half of this decade. At that time, its capabilities for observations in the ultraviolet should certainly be used.

When the OAO is available for planetary work, its use for general observations (apart from the ultraviolet) will apparently be less economical than the use of balloons. The fully active balloon program considered here would require about 1.5 million dollars per year. It is unlikely that an orbiting observatory could be successfully launched for less than 30 million dollars, not even counting the operational costs of telemetering facilities for one year. Although the duty cycle of such a satellite would be greater than that of a series of fifty balloon flights (and this comparison assumes a one-year lifetime for the satellite), it is unlikely that utility of the additional data would be so great as to justify the additional cost. This conclusion is reinforced by consideration of the greater flexibility of instrumentation possible in a balloon program.

Even if the additional data were useful in direct ratio to the quantity, it would be economically desirable to increase the number of balloon flights rather than launch planet-observing satellites to cover the visible and infrared portions of the spectrum.

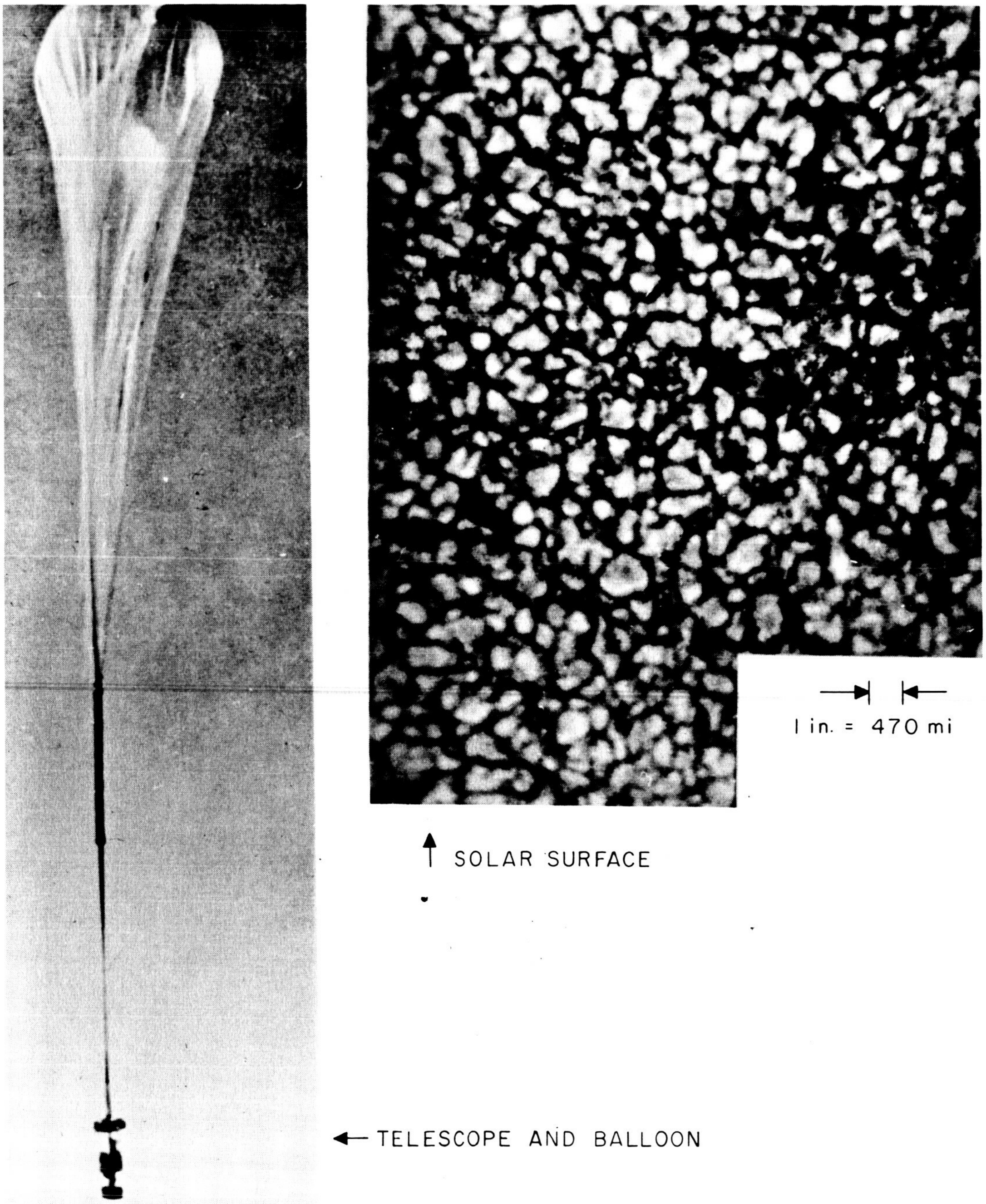

Fig. 4. Project Stratoscope. Schwarzschild's unmanned-balloon instrument and photograph of solar surface obtained by instrument (U.S. Navy photograph)

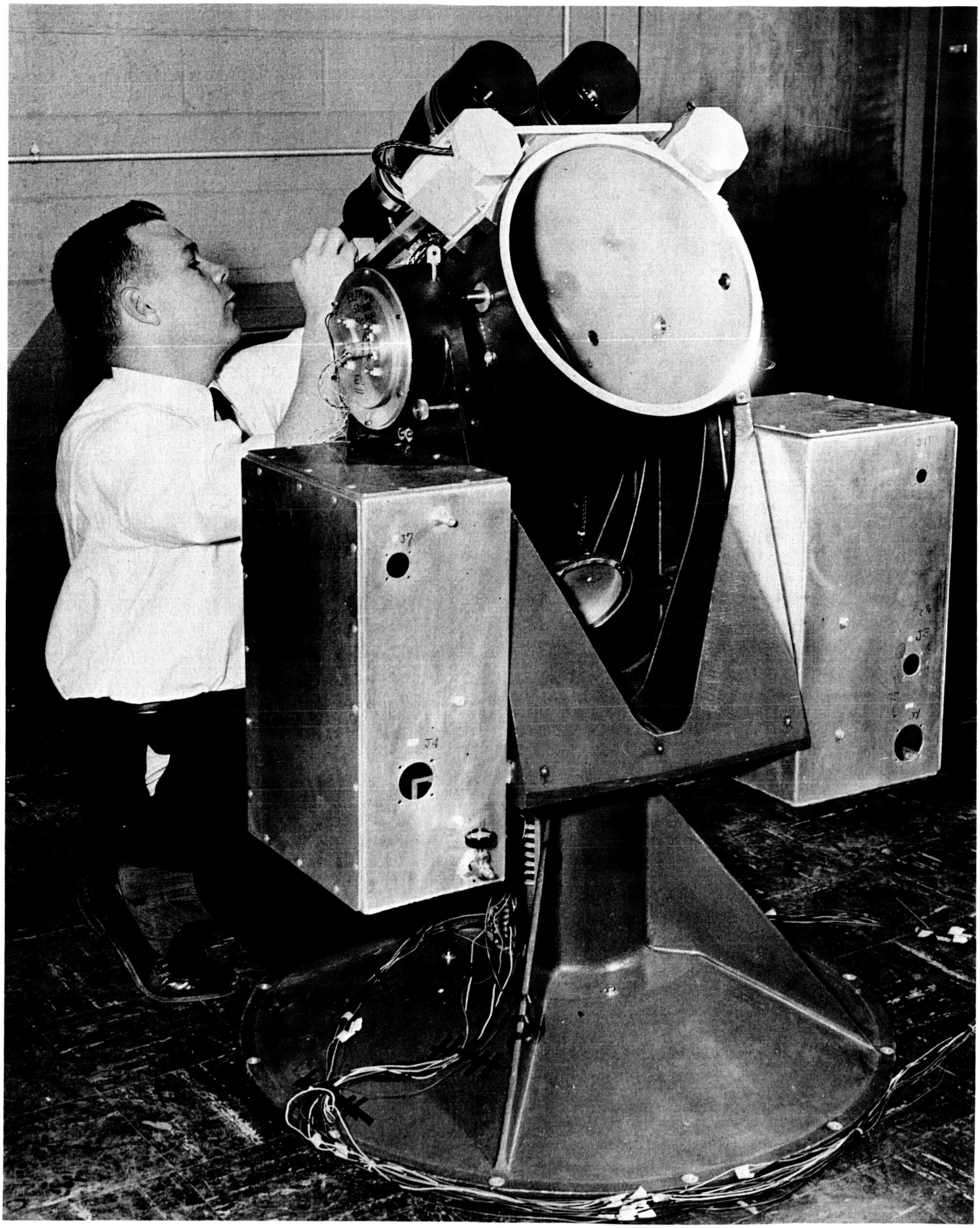

Fig. 5. Stabilization gear for 12-in. Cassegrain telescope (MIT photograph)

V. DATA-ANALYSIS FACILITY AND SCIENTIFIC CENTER

A central facility is needed for the collection and analysis of data, for the exchange and dissemination of information on an efficient basis, and for a locale where geophysicists, astronomers, and those scientists and engineers directly concerned with space-probe experiments can meet frequently for active discussion of mutual problems. The Committee recommends that such a facility be established in the United States, preferably close to, or at, a cooperating observatory or the balloon facility, or that, if occasion warrants, a combined data center and plantetary facility be established. The latter was considered in some detail by the Committee, which recommends it strongly, even though recognizing that the creation of a Planetary Facility is essentially equivalent to establishing an entirely new astronomical observatory, a budget item not to be treated lightly.

The Central Data-Analysis Facility is considered separately from the Planetary Facility, even though their combination into one working unit is highly desirable from the scientific aspect.

Although the need for a data-analysis center is obvious, it must be recognized that the cooperating scientists will wish to process their home observations before transmitting them to a central facility. Clearly, only vitally interested scientists can best gather the original data, and they will have an understandable interest in the interpretation and publication of their own results. This is particularly true of astronomy; each major observatory traditionally publishes its own series of scientific contributions, and observatory staffs will not, in general, consider playing the role of mere suppliers of raw data.

Such an attitude is healthy and is not to be deplored. It is the scientific results which are important, provided that the scientific world has ready access to them. A great inherent difficulty is that each astronomer or isolated group of workers attempts to draw conclusions from the necessarily fragmentary information collected at one station, with generally little or no reference to complementary data obtained elsewhere. The reduction of astronomical data is generally a most tedious process and can be a tragic waste of scientific man hours if modern high-speed methods are not available.

A central reduction center is thus a *sine qua non* in the proposed program of world-wide lunar and planetary observations. Without vitiating the interest and work at individual observatories, it will enable the individual investigators to have access to rapid methods of reduction, to the reductions of complementary observations made elsewhere, and to a quick exchange of information to guide their future work.

A central data-reduction center will further serve to stimulate the production of scientific results and to bring a perspective to bear on the individual work of the network observatories. This will be especially true if the data-reduction center is not just a passive "raw-material" processing and collating organization but is itself a vital contributor to the body of data.

An analysis center combined with a planetary observatory is therefore strongly recommended by the Committee; such a combination would have the further effect of mitigating the academic and "librarian" approach so often associated with data-collecting centers as such. It has been recommended therefore that the Data Analysis Center and Planetary Facility, or the Data Analysis Center alone, if both are not encompassed by the available budget, should be operated for NASA by JPL (either by JPL personnel or by subcontract with an organization or group of organizations capable of carrying out this operation) and should have the following functions:

1. The center would act as a computing section for the entire network, carrying out particularly those aspects of data reduction which cannot be expeditiously carried out at the individual observatories. It would expedite and assist the latter, and often carry out work in parallel, in the instances in which an individual observatory wished to maintain first-order control of its data.

2. It would act as a measuring section for photographs, spectrograms, etc.

3. It would provide information feedback and publication.

4. It would act as a focal point for scientific personnel, bringing together astronomers, geophysicists and related workers, domestic and foreign, for program planning and theoretical research. From time to time, an extended "institute" should be held, emphasizing specific and appropriate aspects of the work.

5. It would form a management and direction center for the observation system to assure that the system operation is in direct support of the NASA–JPL program for the exploration of the Moon and planets.

If a planetary observing facility is included, this additional function should be added:

6. Through its well-equipped observational facility, the center would create new data and make especially those observations which demand highly specialized equipment (the clearly associated balloon facility can so be regarded) or particularly efficient communications facilities, as might be demanded at the time of probe impacts or of ephemeral phenomena on the planets.

The final or terminal function of the Data Reduction Center would be the prompt dissemination of information, both of the immediate type and that represented by the collected, fully reduced results of programs of investigation. These functions can be fulfilled by means of spot-announcement cards, frequent periodic summaries, annual reports, and journal papers.

It is expected that the facility described here would cooperate closely with university and observatory educational programs in the physical astronomy of planets and of the Moon. It would encourage a new generation of astronomers, interested in the physics of the solar system. It should sponsor fellowships and scholarships at various institutes and, by these means, raise the general status of this presently neglected field of physical astronomy. The astronomy, geophysics, and related departments of universities in this and other countries would presumably be the channels for this aspect of the work of the Facility.

VI. STANDARD OBSERVATION KITS FOR COOPERATING STATIONS

The Committee recommends that each of the observatories inducted into the proposed cooperative system be provided with a standard "kit" of instruments for the systematic and intercomparable observation of the planets. It is proposed that such kits be used in addition to the individual and diverse instruments at a given station. They will also be separate from any large, specialized equipment furnished to the observatory by NASA.

The Committee proposes that a special sensing package be developed to permit a complete observation of all features of planetary radiation in rapid succession, relative to any significant planetary rotation phase or other change, in order to permit their interrelation in subsequent analysis. Such a package or kit would be made the basis for standardization and comparison of various observations to be made from different places.

A. Functions of the Observation Kit

The standardized planetary "instrument package" should be adaptable to attachment to a wide variety of telescopes. The unit should be capable of making, in a short period of time as compared to planetary changes (5 to 15 minutes), a series of all of the following kinds of observation:

1. Heterochromatic and narrow-band filter photographs (at a number of standard regions of the spectrum between atmospheric cut-off) of planetary surfaces.

2. Low-dispersion spectra of planetary details. (A suggested method involves holding the planet stationary on the spectrograph slit in order that single planetary details register as streaks along the spectrum.)

3. A standardized photoclectric photometer with filter and diaphragm windows for the measurement of large or small planetary details in all practicable wavelengths.

4. A standardized radiometer for the measurement of thermal radiation of selected planetary details.

5. A polarimeter capable of measuring very weak polarizations.

The proposed standardized kit is not intended in any way to displace specialized equipment, particularly that in which the particular observatory specializes. The instrument kit is to serve two main functions: (1) provide standard systematic observations, particularly of the patrol variety, and (2) effect a calibration of the various stations in the network.

It is suggested that an astronomical seeing instrument, or a similar device, might be included in the standard "kit" furnished to each of the cooperating observatories.

B. Seeing Kit

Since atmospheric distortion will have different effects on observations at the several stations in the system, both on a day-to-day basis and systematically on a seasonal or longer-term basis, it is essential that the "astronomical seeing" at each station is regularly recorded on as objective a basis as is feasible. Therefore, it is recommended that a device for the objective determination of the seeing quality be included in the Standard Observation Kit.

Since, for planetary studies image distortion is of greater consequence than scintillation, an instrument is needed which can measure both (the typical photometer records only scintillation).

It is proposed that each of the cooperating observatories be equipped with identical "seeing meters," and that these be included in the "standard observing kit." Two or three additional seeing meters should be constructed and circulated among the observatories for the purpose of testing possible future observing sites and of tieing-in the present stations with one or more of the long-established large observatories, for control purposes. A study of the "astro-climate" at selected sites would be of very great value to astronomy, even though it is outside the strict scope of the present proposal.

VII. INTERNATIONAL-RELATIONS IMPLICATIONS OF THE RECOMMENDED PROGRAM

The establishment of a world-wide scientific program introduces problems of international relations, both political and scientific. In the instance of this recommendation, questions of national scientific pride will arise in addition to questions of logistics and formal procedures.

Fortunately, the experience gained during the International Geophysical Year (IGY) offers guidance and precedent. Perhaps the closest parallel to the proposed cooperative system is that offered by the network of twelve stations set up by the Smithsonian Astrophysical Observatory for the purpose of the optical tracking of artificial Earth satellites during the IGY. Although establishing this network did not, in most instances, involve arrangements with already existing observatories, but rather the creation of new observatories, it did involve direct relationships with scientific nationals and local and national government authorities.

In the light of this experience, and if the execution of this recommendation is guided by that experience, it appears that increased good will toward the United States and toward our scientists can be generated by the planetary observation system, particularly if the latter is placed upon a truly cooperative basis and care is taken to refrain from any appearance of domination of the science and scientists associated with the member observatories. Particular care should be taken to have nationals of other countries in positions of authority and to have a prevailing spirit of "working with" rather than "working for." It must not be implied in any negotiations that the United States is attempting to buy services, or raw data. With such precautions, it appears to the Committee that the political benefits which might accrue to the United States from the proposed project could be considerable.

No attempt should be made to include Russian observatories in this project, but eventual Russian participation is not precluded and the question should be reviewed periodically. However, there should be no overt attempt to "classify" the proposed project, even in a non-military sense. The best approach would appear to be proceeding with the negotiations on a purely scientific basis and then presenting the project to the scientific councils of the world as a *fait accompli*, with no attempt to withhold the reduced data from the annals of world science. The opportunity for greater scientific interchange between United States scientists and those of the participating countries will be greatly enhanced, particularly as the program of cooperation envisioned is on a relatively continuing basis (10 years appears to be a target figure), after which it may be presumed that a pattern of operation and interchange will be so sufficiently ingrained as to constitute an entity in international science. With respect to administration of the system, the project should be directly sponsored by NASA, with sufficient funds to perform the work adequately, and the administration should be centered in the Data Reduction Center. Nonetheless, the organization should be as loosely knit as possible without detracting from the scientific output. Under no circumstances should there be entertained the concept of a tightly knit "protectorate" of world-wide planetary observations in relation to which the cooperating observatories play a subservient, menial, or purely service role. Although appropriate governmental approval and assurances should and must be obtained, a basic concept should be that of cooperating and participating institutions rather than of governments, and that both scientific and public-relations announcements should be couched in terms of the cooperating institutions as the cogent scientific entities.

In one of two notable cases in the Smithsonian network, the spectre of the struggle for power among scientific administrators in a given country rose up to plague the smooth functioning of the operations. It seems clear that difficulties of this sort need not arise if, at the outset, an uncomplicated, intergovernmental agreement is entered into which sets forth the basic understandings and permits a wide range of academic relationships and freedom for scientific activity. Thereafter, however, actual business should be carried on at the institutional level.

It appears that a simple codicil to already existing cooperative agreements between the United States and other governments for the cooperative operation of scientific observatories and laboratories is all that would be required to make possible the establishment of the proposed network.

Where intergovernmental agreements between the United States and other governments already exist in connection with the utilization of scientific facilities, it would appear that a codicil to such agreements could provide for cooperative action in the operation of planetary observatories and in the exchange of scientific findings and data. Where an arrangement is desired with an institution located in a country where an intergovernmental agreement does not presently exist, NASA should enlist the cooperation of the Department of State in negotiating an approximate agreement, prior to any informal or formal negotiation on the professional or institutional level.

VIII. COMMUNICATIONS FACILITIES AND NEEDS

The communication needs for the planetary observatory system are basically modest. For the most part, data transmission and exchange of program information can be accomplished by mail or newsletter (or at a later time, a journal), and this mode can bear the major load of information exchange.

However, for such critical periods as times of probe intercepts, launchings by other nations, times of unusual solar activity or special alerts occasioned by special planetary phenomena, a state of observational alert must be quickly declared, and rapid communication by cable, radio, or telephone be maintained as necessary during the alert.

A communications facility must, therefore, be maintained in working order (necessitating frequent practice messages) in order that it can function smoothly at critical periods.

The following tabulation summarizes the communications and expected loads for the facility:

MODE I (rapid)
Medium: Radio, Telegram, Telephone

1. Alerts (very fast): 2 or 3 per month
2. Need for intensification of observing effort of specific character (e.g., transient cloud systems, arrival of probe near planet): 2 or 3 per month.
3. Need for activation of balloon flight: 2 to 5 per month.

MODE II (long time)
Medium: Mail or Journals

1. Passage of raw data to reduction center: on a continuing, periodic basis.
2. Distribution of reduced data (first to collector, second to rest of network).
3. Distribution of results of space probes.
4. Distribution of study results (raw data, analysis).
5. Notification of general problem areas.

Reference 10 is a résumé by F. S. Humphrey[4] of worldwide communication facilities and is especially pertinent to the recommended planetary observatory system. The special communications facilities of the Minitrack Satellite Tracking Network, the Smithsonian Baker-Nunn network, and many military communications nets, which are available for use under special arrangement, are also of particular interest in the planning of the planetary observation system.

[4] *A Résumé of World-Wide Communications,* TM 33-31. Jet Propulsion Laboratory, 1960.

APPENDIX

Budget for Ground-Based Balloon-Borne Lunar–Planetary Observation

Item	Amount, thousands of dollars					
	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
I. Optical Network						
Station facilities (6 stations total)	(2 stations)	(1 station)	(1 station)	(1 station)	(1 station)	
Standard kit (50K/kit; 6 kits total)	100	50	50	50	50	
New 40-in. telescopes (200K/telescope; 4 total)		200	200	200	200	
Replacement and repair/year (10% of facilities)		10	35	60	85	110
Special equipment (25K/station)	50	25	25	25	25	
Personnel/year (15K/station)	30	45	60	75	90	90
Contract services/year (17K/station)	34	51	68	84	102	102
Materials and support/year (14K/station)	28	42	56	70	84	84
II. Data Center and Central Observatory						
Operation/year (50K/professional staff member; 10 members total)	100	300	500	500	500	500
III. Balloon Observations		(5 flights)	(15 flights)	(30 flights)	(50 flights)	(50 flights)
Development[a]	500					
Operating contractor/year (20K/man; 5 men total)		20	60	100	100	100
Balloon, gas (10K/flight)		50	150	300	500	500
Controls (10K/flight)		50	150	300	500	500
Recovery (4K/flight)		20	60	120	200	200
Equipment (430K/unit; 3 units total)		430	430	430		
Totals	842	1293	1844	2314	2436	2186

[a]These funds will be over and above current spending for development by NSF, ONR, AFOSR, NASA, NCAR.

BIBLIOGRAPHY

De Vaucouleurs, G. H., *Physics of the Planet Mars*. Faber and Faber, London, 1953.

De Vaucouleurs, G. H., *Reconnaissance and Exploration of the Nearer Planets; Problems of the Terrestrial Planets in the Space Age*. Air Force Missile Development Center, Holloman Air Force Base, New Mexico (in press, 1961).

Humphrey, F. S., *A Résumé of World-Wide Communications*, Technical Memorandum No. 33-31. Jet Propulsion Laboratory, Pasadena, California, December 5, 1960.

Kopal, Z. (editor), *Lunar Compendium*. Academic Press, Limited, London (in press, 1961).

Kuiper, G. P. (editor), *The Atmospheres of the Earth and Planets* (2nd edition). University of Chicago Press, Chicago, 1952.

Sharonov, V. V., "Priroda Planet," *Izdatel'stvo Akademii Nauk S.S.S.R.*, Moscow, 1958.

Smith, J. R., *On the Use of High-Altitude Balloons for Astronomical Platforms*. Raven Industries, Incorporated, Sioux Falls, South Dakota, May 13, 1960.

Strong, J. D., de Vaucouleurs, G. H., and Zwicky, F., *Planetary Astronomy from Satellite-Substitute Vehicles*, Technical Report 60-6. Air Force Missile Development Center, Holloman Air Force Base, New Mexico, March 1960.

Urey, H. C., *The Planets*. Yale University Press, New Haven, 1952.